A Science-Driven Mission Concept To An Exoplanet

Stacy Weinstein-Weiss[1], Marc Rayman[1], Slava Turyshev[1], Abhijit Biswass[1], Insoo Jun[1], Hoppy Price[1], Eric Mamajek[1], John Callas[1], Tim McElrath[1], Dave Woerner[1], John Brophy[1], Mike Shao[1], Leon Alkalai[1], Nitin Arora[1], Les Johnson[2], Merav Opher[3], Seth Redfield[4], Ralph McNutt[5], Carol Stoker[6], Jennifer Blank[6], Douglas Caldwell[7], Louis Friedman[8], Robert Frisbee[8], Gary Bennett[8]

[1]Jet Propulsion Laboratory, California Institute of Technology, [2] NASA Marshall Space Flight Center, [3] Boston University, [4] Wesleyan University, [5] Applied Physics Laboratory, Johns Hopkins University, [6] NASA Ames Research Center, [7] SETI Institute[8], Consultant

Background

- Our success in confirming 3,500 exoplanets, with thousands more to be discovered, begs the question: “When will a spacecraft be sent to investigate?”
- Our study team kicked off in April 2017 to develop a ***mission concept*** and technology development requirements for the first *scientific* robotic exploration mission to an exoplanet
  - Importance of the mission concept: Without the mission concept leading the study, we forget to consider all of the technologies required for the mission
  - Why a science-driven mission? It best answers the question: “What makes a mission to an exoplanet compelling?” and we wanted to develop an extensible architectural framework for the future
    - Note: This does not argue against precursor missions with other objectives
- Our Charge: Think out of the box, be creative, and have fun, but be prepared to back up our innovative ideas with sound physics
- A Multi-center team was established, including academia and independent institutions - JPL, NASA Ames/ Goddard/ Marshall/ Glenn, APL, Boston U., Wesleyan, SETI, 3 consultants

Key System Trades

	Flight Time	TRL	Development Risk	Payload Mass	Pros	Cons	Comments
Mission design							
Fast flyby	Possibly <100 y	2	lower		Minimum ΔV requirement	Encounter time is too short	
Braking at target	>100 y	0	high		Adequate encounter time	Twice the ΔV of flyby	
Propulsion							
NEP	~1,000 y	2	lower	large	Might fit on a single SLS		Requires very high I
Beamed energy sail	Possibly 50 y	2	lower	very small		May require vast infrastructure	Ref. Starshot
Fission pulse	Possibly 200 y	2	high	large			Ref. Dyson Orion pr
Beamed power EP	>500 y	1	high	large	Might fit on a single SLS	May require vast infrastructure	
Fusion pulse	Possibly 50 y	0	very high	large			Ref. BIS Daedelus
Bussard ramjet	Possibly 25 y	0	extreme	large	Minimal propellant required	No credible concepts	
Antimatter rocket	Possibly 25 y	0	extreme	large		No credible concepts for storing antimatter or directing thrust	
Telecom							
Optical com		4	lower				
Large aperture μ-wave		3	moderate		Might integrate with a sail	Difficult to maintain shape	
Power							
Radioisotope		6	low				
Fission		4	moderate				
Beamed		1	high				
Antimatter		0	extreme				

Key Mission Concept Requirements - 1

1. The flight time to the target must be < 50 years, pending confirmation of a suitable target

- **Rationale: The mission must be politically and humanly palatable**

2. There shall be meaningful science return at least every decade en route to the exoplanet

- **Rationale: There should be a mission conducted during the flight to the exoplanet to keep the science community engaged**

3. The primary objective of the mission shall be to confirm and characterize life at the exoplanet

- **Rationale: Per NASA's strategic objective: Discover how the universe works, explore how it began and evolved, and <u>search for life on planets around other stars</u>**

Key Mission Concept Requirements - 2

4. The threshold data shall arrive at Earth within <70 yrs from launch

- **Rationale: The threshold data must come back within the professional lifetime of someone born around launch; this person can grow up learning about the mission and be inspired by it, and eventually join the team and be ready to interpret the data when it comes back to Earth**

5. The first bit of exoplanet science data shall arrive at Earth 5 – 10 yrs after exoplanet arrival

6. The exoplanet target shall be within 15 LY of Earth

- **Rationale: If the spacecraft is travelling at a low fraction of the speed of light (0.1 – 0.2c), the exoplanet target must be within 15 LY of Earth (50 yr travel time and 10 - 20 years) to send back the threshold data**

Key Mission Concept Requirements - 3

7. Per the 100th anniversary of Apollo, the launch date shall be no later than July 15, 2069

- **Rationale: Rep. Culberson, who is a champion of an interstellar mission, proposed this!**

Key Mission Concept Assumptions

- The exoplanet target has been previously observed and resolved 1000x1000 pxl or to 1 pxl with promising bio-signature lines
  - We will have an idea of which instruments to bring and their performance specifications
  - We will have TBD accuracy on the ephemeris

- We are not constrained to today's technology, but there shall be a reasonable, physics-based path toward realizing the needed technology
  - Example: Flying 3-D printers to replace worn parts
  - Trying to stay away from ”and a miracle occurs…”

Key Finding

- **In response to an early driving question:**
  - ***What makes this mission compelling (in terms of science return) with respect to what we will be able to do in a few decades with near-Earth large telescopes, enormous space-based interferometers, and/or a mission to the Solar Gravity Lens Focus?***

The team determined that much of what we traditionally learned from reconnaissance missions will be gleaned from future near-Earth telescopes or a mission to the SGLF, leaving one big science goal:

To confirm and characterize life

To Confirm and Characterize Life

- This objective was profound and drove the study architecture
- Biosignatures (as we know them today) cannot confirm life
  - Recent paper[1] showed how Proxima Centauri Beta, in it's star's habitable zone, could have an O_2 atmosphere but no possibility of life due to massive solar wind exposure
- The only[2] method today of confirming life is to land and sample
  - This drives the mission to at least slow down and most probably to brake and orbit to perform landing site selection and deploy a lander, which in turn severely limits our know propulsion options
  - This does not preclude precursor flyby missions to explore the interstellar medium (ISM) and/ or validate key technologies
    - Exploration of the ISM is a required precursor to the exoplanet mission in order to better characterize the ISM environment to inform system design

[1] *Schwierteman et al., Identifying Planetary Biosignature Impostors: Spectral Features Of Co And O4 Resulting From Abiotic O2/O3 Production, Astrophysical Journal Letters 819:L13, 2016, doi:10.3847/2041-8205/819/1/L13*

[2] *Aside from seeing lights turning on and off in images or SETI contact*

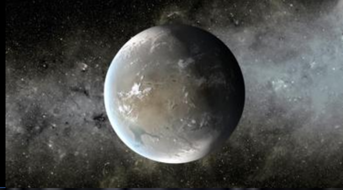
Target Selection - 1

- With over 3000 candidates to select from today, and thousands more in the future, selection criteria for choosing the target exoplanet will be important
- These criteria will evolve with our understanding of life and habitability
- The exoplanet characterization required to meet the criteria the implementation of large near-Earth telescopes that are currently in the Astronomy and Astrophysics roadmap
- A mission to the Solar Gravity Lens Focus is also highly desired, if not required, for characterization

Target Selection - 2

- Given our knowledge today, the following target selection criteria were suggested:
  - Exoplanets that are in their Sun's Habitable Zone
  - Exoplanets with masses < 2 Earth masses (rocky planets with a decent chance for an atmosphere)
  - Exoplanets that experience roughly the same solar radiation as our Earth
  - Detection of a biosignature from the exoplanet plus at least 1 pixel image of the exoplanet (ideally 1000 x 1000 pixel image)
  - The current age and expected lifetime of the star should be such that life will have had a chance to form
    - Current thinking is that the star should be at least [4-5] Byr old
  - The exoplanet's star should be close to a G2V Class (our Sun)

Science Objectives



- Ultimate objectives will be determined by Decadal Survey and NASA Working Groups

- 5 main categories of science objectives suggested:
  - Heliosphere Boundaries
  - The Interstellar Medium (ISM) and other Science En Route
  - Astrosphere of the Target Star
  - The Solar System of the Target Exoplanet
  - The Target Exoplanet

Instrumentation

- First 3 categories can be achieved with mostly the same instrumentation (similar to Voyager, with informed measurement requirements)

- Science objectives involving the solar system of the target star are numerous and involve the typical basic reconnaissance/ characterization objectives that missions in the solar system have had
  - Composition and mapping, atmospheres, moons, rings, dust, asteroids/ comets, refinements of size and mass, spin rates, etc.

- Science objectives involving the target exoplanet can include many of the basic categories listed above
  - An orbiting mission can resolve rivers, forest, deserts, and oceans.
  - A key mission requirement is to confirm and characterize life, which requires to be developed life detection experiments on a lander
  - Other landed instruments include imaging cameras, metrology station

Mission Concept Architecture Highlights

- 2-stage light sail for propulsion
  - Allows stopping at the exoplanet
  - Easiest propulsion technology development path
  - Only option that doesn’t require massive on-board power
  - Lasers at Earth can be improved over mission lifetime
- 2.5-m on-board lasercomm system
  - 100-m lightbuckets in space
  - Onboard power of 3.5 kW for 100 bits/sec downlink
- Autonomous on-board navigation
  - Required due to one-way light times of years
  - Proven on Deep Impact
  - NEW: on-board autonomous mission replanning capability (think autonomous landing site selection and execution)

THE STARS ARE CALLING AND WE MUST GO

Backups

Meetings

Session	Topic
1	Kickoff
2	Mission Objectives
3	Science Objectives
4	Target Selection and Expected Apriori Target Knowledge
5	Interstellar and Exoplanet Environment
6	Instrumentation
7	Communication
8	Propulsion
9	Power
10	Navigation
~~11~~	~~Operations/ Autonomy~~ (Ran out of time)
12	Wrap-Up

Team Member	Discipline	Org	Email
Stacy Weinstein-Weiss	Lead	JPL	Stacy.S.Weinstein-Weiss@jpl.nasa.gov
Marc Rayman	Mission Engineering	JPL	Marc.D.Rayman@jpl.nasa.gov
Phil Willems	Exoplanets	JPL	Phillip.A.Willems@jpl.nasa.gov
Les Johnson	Propulsion	NASA MSFC	les.johnson@nasa.gov
Tim McElrath	Navigation	JPL	Timothy.P.Mcelrath@jpl.nasa.gov
Merav Opher	ISM Science	Boston U	mopher@bu.edu
Seth Redfield	ISM Science	Wesleyan	sredfield@wesleyan.edu
Robert Shotwell	7x Chief Eng	JPL	robert.f.shotwell@jpl.nasa.gov
Ralph McNutt	Interstellar Physicist	APL	Ralph.McNutt@jhuapl.edu
Tupper Hyde	Mission Eng/ Systems Analysis	NASA GSFC	tupper.hyde@nasa.gov
John Brophy	Propulsion	JPL	john.r.brophy@jpl.nasa.gov
Leon Alkalai	Strategic Planning	JPL	leon.alkalai@jpl.nasa.gov
Nitin Arora	Mission Design	JPL	Nitin.Arora@jpl.nasa.gov
Slava Turyshev	Astrometry	JPL	turyshev@jpl.nasa.gov
Mike Shao	Astrometry	JPL	michael.shao@jpl.nasa.gov
Abi Biswas	Laser comm	JPL	Abhijit.Biswas@jpl.nasa.gov
Dave Woerner	Power	JPL	david.f.woerner@jpl.nasa.gpv
Insoo Jun	Environments	JPL	Insoo.Jun@jpl.nasa.gov
Hoppy Price	System Engineering	JPL	humphrey.w.price@jpl.nasa.gov
John Skok	Resource Utilization	ARC/ SETI	john.r.skok@nasa.gov
Ruslan Belikov	Exoplanets	ARC	ruslan.belikov-1@nasa.gov
Doug Caldwell	Exoplanets	ARC/ SETI	douglas.caldwell@nasa.gov
Jen Blank	Astrobiology/ Instrumentation	ARC	jennifer.g.blank@nasa.gov
Carol Stoker	Life in Extreme Environments	ARC	carol.r.stoker@nasa.gov
Eduardo Bendek	Exoplanet Char. Instrumentation	ARC	eduardo.a.bendek@nasa.gov
John Callas	Exoplanets Office	JPL	John.L.Callas@jpl.nasa.gov
Robert Frisbee	Advanced Propulsion	JPL (ret.)	frisbeedrbob@aol.com
Eric Mamajek	EXEP Deputy Program Scientist	JPL	Eric.Mamajek@jpl.nasa.gov
Lou Friedman	Mission Architecture	JPL (consultant)	Louisfriedman@gmail.com
Samuel Harrison	Student	ISU	samuel.m.harrison@nasa.gov
Gary Bennett	Power and Propulsion	Consultant	useresg4282@aol.com
Robert Cataldo	Power	NASA Glenn	robert.l.cataldo@nasa.gov

Intelligent Life?

- A Solar Gravity Lens mission with 10 km imaging resolution could plausibly detect artificial illumination, if present.
- However, the exoplanet may be a world where there is not yet advanced intelligent life to produce electric light.
  - Intelligent life capable of producing lights, radio signals, structures, etc. only recently appeared on the Earth and so there is a low chance of finding life in that state.
  - Those technologies have only existed on Earth for about 100 years. So for the Earth, advanced intelligent life has only been detectable on a world with a measurable bio-signature for 1 part in 5 million (~2x10-7).
- Thus, as a proxy for other exo-worlds, there is a very small likelihood of finding advanced life, and there is a very small number of candidate exo-worlds available within 15 LY.
- Although photosynthetic life on Earth started at least 3.5 BY ago, the presence of free O_2 in the Earth’s atmosphere (a potential bio-signature) has been present for less than 1 BY.